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Joint GOFC/GOLD Fire and IGBP-IGAC/BIBEX Workshop

Improving Global Estimates of Atmospheric Emissions from Biomass Burning

Executive Summary

Accurate quantification of the amounts of trace gases and particulate matter emitted from vegetation fires and other sources of biomass burning (agricultural waste and biofuels) on a regional and global basis is required by a number of users, including scientists studying a wide range of atmospheric processes, national governments who are required to report greenhouse gas emissions, and those interested quantifying the sources of air pollution that affect human health at regional scales. Over the past decade, improvements in the ability to detect and map fires using a number of different satellite systems have been achieved, largely through efforts coordinated through working groups organized by the IGBP Data and Information System and Global Observation of Forest Cover (GOFC) projects. In addition, significant advances and improvement in or understanding of the emissions factors for biomass burning in different biomes has resulted through efforts by the Biomass Burning Experiment (BIBEX) organized through the International Global Atmospheric Chemistry project. A number of satellite-based fire data products have been generated, and a number of new products will shortly be available. These new data products will provide the basis for estimating emissions from biomass burning on a global basis. However, a number of issues remain concerning the availability of other data sets needed to generate these estimates. Recognizing these issues, the GOFC-Fire Satellite Validation Workshop (held in Lisbon, Portugal on 9-11 July 2001), recommended that a workshop focusing on *Improving Global Estimates of Atmospheric Emissions from Biomass Burning* be organized. This workshop was held from 17-19 July 2002 on the campus of the University of Maryland, College Park, Maryland. This workshop served as the annual meeting of the GOFC/GOLD-Fire Program.

The overall goals of the meeting were to review the information products generated from satellite imagery and other sources that are currently available for developing emission estimates from biomass burning, evaluate areas where improved or additional products would be beneficial, and recommend products for use by the atmospheric science community. Specific objectives of the workshop were to:

1. Examine the current methods and approaches for estimating emissions from vegetation fires and biomass burning
2. Present recent emissions estimates and determine the best estimates of biomass emissions, according to major biomes
3. Identify current uncertainties and necessary improvements
4. Refine the scientific requirements for observations and data products needed to reduce the uncertainties
5. Recommend emissions products for a BIBEX-sponsored international model inter-comparison to evaluate our scientific understanding of the effects of biomass emissions on the concentrations of trace gases and aerosols in the atmosphere

6. Examine possible operational approaches for generation of input and output products for emissions models.

The workshop was organized into a series of plenary sessions, poster sessions and breakout discussions. Over seventy people participated in the workshop, with 17 overview presentations and some 40 poster presentations.

The major **Findings** and ***Recommendations*** of the workshop include:

Estimating Global Emissions from Biomass Burning

Findings
Current approaches for estimating global emissions are limited by accurate information on area burned and fuel available for burning. Recent burned area products developed from satellites and compilation of ground-based data provide the basis for several ongoing efforts to produce new estimates of global biomass burning emissions. Further improvements in global estimates will be based on advanced information products from regional/biome specific studies.

Recommendation
An inter-comparison between global- and regional-scale models should be carried out in the near term in order to provide the user community with the means to assess the usefulness and uncertainty of these products. The estimated emissions and range of emissions should be used in a global model inter-comparison study in order to assess the consistency between estimated emissions and observations of atmospheric constituents.

Estimating Emissions from Biomass Burning in Tropical Forests

Findings
The accuracy of estimates of emissions from fires tropical forests is low due to: (a) the complexity of mapping active fires in this biome using satellites; (b) estimating seasonal area burned; and (c) quantifying the levels of fuels available for burning, which varies between: (1) different regions and forest types; and (2) as a function of land use practices.

Recommendation
Reducing uncertainties in estimates of biomass burning emissions requires continuation of research efforts to address these issues in all the major areas where tropical forests exist (South America, Africa, Asia).

Estimating Emissions from Biomass Burning in Savannas and Shrublands

Findings
Studies focused on estimating emissions from savannas/shrublands are well advanced, and the means to produce estimates of seasonal area burned in this biome should emerge over the next several years. Through a coordinated effort, the scientific community should be

able to produce improved estimates of emissions from this biome over the next two to three years.

Recommendations
Efforts to produce a global area burned (burn scar) products from systems such as MODIS and SPOT VEG need to continue, along with the appropriate validation activities. A coordinated program directed towards development and comparison of estimates of emissions for savanna regions needs should be instituted.

Estimating Emissions from Biomass Burning in Temperate Forests

Findings
The fire science and management communities have carried out the numerous studies of fires and fuel loads in this region which provide a basis for estimating emissions from vegetation fires. While this community has also maintained records on fire activity which produce some information on area burned, these data sets do not document all types of fire, nor has the accuracy of these data been assessed. Thus, the ability to generate accurate estimates of emissions in this region is not high at this time.

Recommendations
Efforts are needed to document and quantify the area burned in the temperate forest region, including: (a) urging a more complete accounting of area burned in all vegetation types by individual countries, rather than just reporting forest area burned; and (b) integration of satellite observations of fire activity with traditional methods of fire mapping to produce improved area burned estimates. Fuel load and/or biomass/carbon density maps need to be generated for all temperate regions where fires occur, as well as information on fire type and fire severity. These efforts should be carried out at a regional level (e.g., Europe/Western Russia, southern Asia [Mongolia/China), and the conterminous U.S.).

Estimating Emissions from Biomass Burning in Boreal Forests

Findings
Efforts to produce burned area products through the integrations of ground-based data records and satellite data products are well underway in most of the boreal forest region. Based on existing forestry and soil databases, and existing fire behavior models, improved estimates of emissions from boreal fires are now being produced. Major uncertainties in these estimates exist due to: (a) uncertainties in area burned for western Russia; (b) documenting the patterns of fire behavior and fire severity; and (c) quantification of the levels of consumption of surface fuels, particularly the consumption of organic soils in forests underlain by permafrost and boreal peatlands.

Recommendations
Generation of more accurate fire maps for western Russia using satellite imagery needs to be carried out. A burned area map for Russia back to ~1980 should be generated using AVHRR data. Comparison and integration of different satellite and ground products in North America

should continue. A systematic refinement of fire behavior, fire severity, and fuel consumption models using satellite data should carried out. Studies of area of peatland burning and levels of organic soil burned need to be initiated.

<u>Improved communication and coordination between the modeling and observation communities</u>

Findings

The workshop concluded that the communication between the atmospheric modelers and those responsible for generating remotely sensed data products and emissions estimates had been extremely useful. The information requirements from the atmospheric modeling community in terms of the characteristics of the necessary data sets to provide improved emissions estimates are not well developed. The input products used in emissions modeling and the model output are often unvalidated (i.e. with no known accuracy), which hinders their quantitative use.

Recommendations

There is the need for a continued dialogue between the atmospheric modeling community and the remote sensing and emissions modeling communities to guide the improvement of the products and their use. There is a need for a clearly articulated and supported set of data requirements from the atmospheric modeling community. The products generated by the remote sensing community, the ground based maps and estimates and the emission model outputs need to have associated quantitative accuracy statements and recommended guidelines for data use. Involving regional scientists with local knowledge on fires and biomass burning emissions in the development and assessment of product accuracy is strongly recommended. The proposed model inter-comparisons identified above would provide an opportunity to address data requirements and product accuracy.

<u>Operational Provision of Data Sets to Estimate Biomass Burning Emissions</u>

Findings

Currently the generation of biomass burning emissions estimates and the associated data sets fall within the research community. The satellite data sets are largely experimental. Research projects are short-term and cannot be relied upon for continued data provision. The provision of long term, multi-year data sets of emissions are needed for global change research and the policy communities. The roles and responsibility for the provision of operational long term data sets on fire emissions are currently unclear.

Recommendations

The funding agencies are encouraged to support research into improving global biomass burning emissions and their impact on atmospheric chemistry. As the methods and techniques for emission estimates become robust, there is a need to transition them to a more operational environment and secure the long-term provision and stewardship of data sets on biomass burning emissions. The appropriate national and international operational agencies

responsible for the provision and management of biomass burning emissions data need to be identified and a strategy developed for global data set provision, validation, compilation and management.

Utilization of Data Sets to Support International Policies

Findings

Data sets are needed to support the formulation of policies for sustainable management of the Earth system to reveal those human-induced changes of fire regimes, fire-induced degradation of ecosystems and land-use systems that result in exceeding natural or acceptable budgets and environmental and humanitarian impacts of pyrogenic emissions, including the impact of smoke on human health. The implementation of international conventions and strategies that address the prevention or mitigate the negative consequences of vegetation fire emissions require a multi-sectoral and interdisciplinary approach and need to be supported by data sets. There is a need for an improved interface between the science and policy communities, to facilitate effective use of the data sets, for example through such mechanisms as a clearing house for information

Recommendations

The information requirements for the implementation of international conventions and strategies that address the negative impacts of vegetation fires must be formulated jointly by the research community, the international conventions and the agencies and programmes of the United Nations and other international bodies involved in sustainable management of the Earth system. The United Nations and the donor community are encouraged to actively support international coordination efforts by the Inter-Agency Task Force for Disaster Reduction of the UN International Strategy for Disaster Reduction (ISDR), Working Group on Wildland Fire and the GTOS GOFC/GOLD Program in their coordinating efforts at global and regional levels to reach consensus in the formulation of procedures and methodologies to further develop and utilize vegetation fire data sets for the benefit of humankind.

Meeting Summary

Three breakout sessions were used to address the goals and objectives of the workshop. Each breakout session was organized into three sub-groups to discuss estimating emissions from global wildland fires: (a) on a global basis; (b) in savannas/shrublands and tropical forests; and (c) in temperate and boreal forests. The three breakout sessions were initially guided by the following questions:

Breakout Session 1 – Review Current Status of Emission Estimation Procedures / Quantification of Emissions

1. Do we have the ability today to generate biomass burning emission estimates over a five-year period (say 1997 to 2001) at the spatial (e.g., 1 by 1 degree or 0.5 by 0.5 degree grids) and temporal scales (e.g., weekly, bi-monthly) required by atmospheric modelers and other users of this information?
2. How well do the emission estimation procedures (models) currently account for the unique characteristics of biomass burning in different regions of the world?
3. What are the major sources of uncertainties in emission estimation procedures (models)?
4. What are the information needs for reducing these uncertainties?

Breakout Session 2: Status of Emission Estimation Procedure (Model) Inputs

1. How well do existing information products fulfill the input requirements for biomass burning emissions emission estimation procedures (models)?
2. In terms of improving the accuracy of biomass burning emission emission estimation procedures (models), what input parameters should be given highest priority?
3. What role do satellite observations have in terms of reducing the uncertainties in estimating emissions from biomass burning?

Breakout Session 3: Recommendations for Improved Production of Emission Estimates

1. What steps could be taken in the near term (1 to 2 years) to improve the accuracy (reduce uncertainties) of these estimates?
2. What steps (including research) need to be conducted over the next 3 to 5 years to improve the accuracy (reduce uncertainties) of these estimates?

Finally, a more detailed summary from each breakout group is presented below

Global Breakout Group

The members in this group included atmospheric scientists who represent a major user of emissions estimates from biomass burning, as well as scientists involved in the generation of the emission estimates. There were representatives from five groups who have already or will be shortly generating estimates of emissions from biomass burning at a global scale. The initial

findings of this group included during the first breakout session included: (1) the required global emissions modeling approaches and outputs were dependent on the end user, but overall, it was recommended that outputs be at a fine grid scale (0.5° by 0.5° or 1° by 1°) at a weekly time scale; (2) the estimation of emissions on a global scale is still limited by availability of accurate area burned information; (3) a number of approaches are currently being used to account for variations in fuel loads and combustion characteristics; and (4) improvements in 3 are most likely to come from biome specific modelers.

Based on this last finding, the group recognized that addressing the questions posed for the second breakout session would be difficult. However, since it was discovered that a number of efforts were currently underway to generate global emissions estimates, it was decided to discuss a framework for conducting an inter-comparison between different emissions estimation approaches so that the end uses have a better understanding of the sources of variation. Breakout session 2 was devoted to developing this framework.

It was recommended that areas ~3° by 3° in size be selected from regions or biomes where biomass burning is known to occur. These areas should contain the same overall vegetation cover, and included the following major biomes (regions): (a) savannas/shrublands (South Africa, Australia, India, South America, Mongolia [steppe]); (b) tropical forests (Brazil, Central Africa, Indonesia); (c) temperate forest (western U.S., southeastern U.S.); and (d) boreal forest (western Canada, northern Siberia, southern Siberia, Russian Far East). For each region, each participant would provide both model inputs (average biomass/carbon density or fuel density, combustion efficiency or fraction of biomass/carbon consumed) and outputs (average carbon release per unit area burned).

It was recognized by this group that significant efforts are also underway to generate emissions at regional scales as well. It was recommended that the emission estimation inter-comparison also include these regional approaches as well.

Improvements in emissions estimates might be possible through a detailed comparison of outputs from global atmospheric aerosol and chemistry models with direct observations of the products of biomass burning, such as those produced by MOPPITT and other satellite systems. These comparisons should be feasible because the emissions from biomass burning represent a large perturbation to global atmospheric chemistry, especially in the tropics. Satellite observations have revealed elevated levels of O_3 and CO over vast areas of Central and Southern Africa and South America, over the tropical Atlantic, and the Indian Ocean. This is due to biomass burning, which represents a major global source for a number of important gases, including CO_2, NO, CO, and CH_4, as well as aerosols. The availability of new satellite measurements for aerosols, CO, NO_2, and VOCs provide a basis by which to improve estimates of biomass emissions by comparison of predicted concentrations with measurements. We recommend that the set of biomass emissions and estimated ranges of emissions derived from the emissions inter-comparison be used in a global atmospheric aerosol/chemistry model inter-comparison study. The study should involve a single set of emissions and range of emissions and should include output from both aerosol models and tropospheric chemistry models. This model and measurement intercomparison should be updated as new burn-scar products and vegetation-cover and density products become available.

Tropical Forests and Savannas Group

This group represented largely those interested in modeling emissions from fires in tropical and sub-tropical regions largely found south of 30° N latitude. Biomass burning in this region is largely the result of anthropogenic activities, including those associated with forest and land clearing, agriculture, and maintaining of lands for grazing of livestock. While biomass burning occurs in a large number of vegetation types in this region, issues associated with estimating emissions from these fires were discussed using the two representative biomes of this region: tropical forests and savannas.

With respect tropical forests, there are still several major information requirements that need to be met in order to estimate emissions from biomass burning in this region. First, biomass burning in this region is very closely tied to clearing of land which in turn, occurs at scales that are not easily detected using moderate-resolution remote sensing systems (e.g., MODIS). In addition, it is known that under-canopy burning also occurs in tropical forests, a process that is difficult to detect using satellite remote sensing. While fires in tropical forest regions can be detected using a variety of satellite remote sensing techniques, converting these observations to estimates of area burned is a particularly difficult problem. Continued research in this area is needed to resolve these issues. Another issue that needs to be addressed in tropical forests is the process through which biomass is burned. Land clearing in tropical forests occurs through repeated burning of the same areas. The actual rates patterns of this "slash and burn" are different in different regions (e.g., South America, Africa, Asia), depending on forest type, government policies, and cultural practices. In summary, while it is known that biomass burning in tropical forests is a key source of emissions, considerable additional research efforts need to be carried out to improve our ability to accurately estimate these emissions.

The participants of this group presented a much more optimistic prognosis for estimating emissions from burning of savannas. Fires in this biome are largely the result of human activities, and typically cover large areas. Although the scars from these fires are short-lived (limited by rapid vegetation regrowth after burning), satellite remote sensing techniques are advancing to the point where they can be accurately mapped. Current state-of-the-science can produce emissions estimates for savannas is a 0.5° x 0.5° grid at a monthly time-step, with an accuracy thought to be on the order of $\pm$60%. It is felt that by the end of 2004, emissions of various trace gases and particulates (e.g., CO, CH_4. PM2.5, CO_2) could be produced on 0.25° x 0.25° grid every 8 days over an 18 month period, with a known accuracy < $\pm$30%.

In order to produce these emission estimates, the following items are required: (a) a validated, 500 m resolution, 8-day burned area product for all savanna areas (accuracy of $\pm$10%, unbiased); (b) at least 3 consecutive years of burned area to get fuel loads to an accuracy of $\pm$ 25% (implies development and validation of dynamic, spatially-explicit fuel load models); (c) simultaneous precipitation estimates at a 0.25° x 0.25° grid; and (d) development of a rigorous error propagation method.

The procedure recommended by this group to achieve these emissions estimates includes development and comparison of several different modelling approaches. Each model should be

modular in form to allow for sub-model inter-comparisons, including comparison of fuel loads, emission factors, completeness by (standardising one component at a time). Case studies should be carried out that include both top-down versus bottom-up approaches (e.g., multi-tracer, multi-constraint [CO, Aerosol, Ethane, use of actual fire events such as Sidney fires, River of Smoke, Timbavati, etc., carried out over a two-week period in a small region, e.g.). Finally a one-year budget closure experiment should be carried out for all savanna regions between 35° N and 35° S Latitude, using multi-temporal (monthly) aspects to help resolve outstanding disagreements between models.

Temperate and Boreal Forest Group

In addressing the questions presented for the breakout groups, this group provided the following answers: Based on existing area burned and forest biomass databases, it is now possible to produce global emissions estimates for the extra-tropical northern hemisphere region originating from wildland fires. It should be noted that estimating emissions from prescribed fires and agricultural burning is more problematic because of the lack of information on area burned in these fires. The group noted that there is high inter-annual variability in area burned in this region; therefore average annual emission estimates will not be a useful product. A minimum of five years worth of data are needed to characterize emissions in this region.

Most of the emissions in this region originate from fires in North America and Eastern Eurasia, with our confidence in the former higher in the latter because of the lack of information on area burned in the latter. However, satellite data sets are now emerging to provide better area burned estimates in Eastern Eurasia. Factors that further limit the accuracy of emissions from this region are a lack of precise maps of fuels loads at the higher resolutions (<100 m) required to map the complex patterns of forest and peatland cover in this region. Such products can be provided by finer resolution satellite data sets, such as Landsat imagery. The ability to quantify types of fires (crown versus ground, flaming versus smoldering) further limits the accuracy of emission estimates, as well as determining the injection height of the emissions into the atmosphere. In boreal regions, quantifying the level of deep smoldering fires occurring in organic soils is an important information need. Additional factors, such as crown consumption percentage, need to be explicitly involved in the modeling framework. A thorough assessment of these various factors and a sensitivity analysis of the final emission estimates need to be performed. Inconsistencies in the terminology also need to be eliminated.

A regional approach is recommended for improving emissions in these two biomes. Mapping burned area in the region is no longer of highest priority, but priorities vary by region. In particular, continued efforts to map fire locations, timing and boundaries in the eastern part of Eurasia and western Russia is needed, and the accuracy of fire information in other parts of Eurasia and North America needs to be assessed. Efforts need to continue to map fire fuels at higher spatial resolutions. Additional information on fire behavior, levels of biomass and organic soil carbon (especially peatlands), and fuel consumption is also needed in all regions. More field work and advanced remote sensing techniques are needed to reduce uncertainties.

The connection between data collection and scientific assessment needs to be improved in all regions. Satellite data provide a current assessment of area burned, while ground-based *(in situ)*

estimates are often available only at the end of the season, and in some cases may be incomplete. The *in-situ* and remote sensing data need to be utilized in an integrated approach to maximize the accuracy of information.